WYOMING FOSSIL FUELS FOR THE 21ST CENTURY

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ABSTRACT

Wyoming's petroleum industry produced 1.2 trillion cubic feet of natural gas and 63.2 million barrels of oil in 1998. Over the last 10 years Wyoming's proved reserves of natural gas have risen from 10.3 to 13.6 trillion cubic feet despite production of 10.1 trillion cubic feet over the same period. Production of natural gas, including coalbed methane, is projected to reach 1.4 trillion cubic feet by 2005. Additionally, Production of natural gas liquids is projected to reach 40 million barrels and production of crude oil will be about 42 million barrels in 2005.

The Wyoming coal industry produced over 300 million short tons of coal in 1998, and production is projected to reach 365 million short tons per year by 2005. Today, 97% of Wyoming coal is used to feed coal-fired power plants in 29 states, Canada, and Spain. Future constraints on Wyoming coals, such as environmental-political policy changes and transportation availability, will provide more opportunities for coal-derived liquid fuels (LFC) and solid fuels from coal (SFC) processes.

INTRODUCTION

Wyoming is well positioned to supply fossil fuels for the United States' energy needs into the 21st century. By the year 2005, Wyoming's coal production should reach 365 million short tons (mt) (Figure 1), natural gas production should almost reach 1.4 trillion cubic feet (tcf)(Figure 2), natural gas liquids production should reach 40.0 million barrels (mmbbl) (Figure 3), and crude oil production will decline to about 42.0 mmbbl (Figure 4). For comparison, Wyoming's coal production in 1998 was 300 Mt, natural gas production was 1.2 tcf, natural gas liquids production was 36.0 mmbbl, and crude oil production was 63.2 mmbbl. Among all of the states, Wyoming is first in reserves of coal, third in reserves of natural gas, fifth in reserves of natural gas liquids, and sixth in reserves of crude oil (Table 1).

OIL, NATURAL GAS, AND NATURAL GAS LIQUIDS

The first commercial oil well in Wyoming was completed in 1884 near an oil seep. Over 1,600 oil and gas fields have been discovered in Wyoming since that time, and those fields have produced 6.5 billion bbl of oil, 23.6 tcf of gas, and over 500 mmbbl of natural gas liquids.

In Wyoming, oil and gas are produced from reservoirs of Tertiary, Cretaceous, Jurassic, Triassic, Permian, Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian age. Commercial oil and gas production comes from every major basin and the Overthrust Belt of western Wyoming (De Bruin, 1996).

Over 75 % of Wyoming's present oil production comes from the Powder River, Bighorn, and Wind River basins (Figure 5) and is concentrated in reservoirs that are Cretaceous, Jurassic, Permian, and Pennsylvanian in age (De Bruin, 1993). The main oil reservoirs are the Cretaceous Shannon Sandstone, Sussex Sandstone, Frontier Formation, Muddy Sandstone, and Dakota Sandstone; the Jurassic/Triassic Nugget Sandstone; the Permian Phosphoria Formation; the Permian and Pennsylvanian Minnelusa Formation; and the Pennsylvanian Tensleep Sandstone (De Bruin, 1996).

Over 85 % of Wyoming's present natural gas liquids and natural gas production comes from the Overthrust Belt, Green River Basin, Great Divide Basin, and Washakie Basin (Figure 5), and is concentrated in reservoirs that are Tertiary, Cretaceous, Jurassic, and Mississippian in age (De Bruin, 1993). The main natural gas liquids and natural gas reservoirs are the Tertiary Fort Union Formation; the Cretaceous Lance Formation, Frontier Formation, Almond Formation, Muddy Sandstone, and Dakota Sandstone; the Jurassic/Triassic Nugget Sandstone; and the Mississippian Madison Limestone (De Bruin, 1996).

Wyoming's proved reserves of crude oil declined from 0.928 billion bbl in 1980 to 0.627 billion bbl in 1997. Production of crude oil during that period was 1.6 billion bbl. Proved reserves of natural gas increased from 9.100 tcf in 1980 to 13.562 tcf in 1997 despite production of 15.1 tcf over the

same period. Proved reserves of natural gas liquids increased from 0.239 billion bbl in 1980 to 0.600 billion bbl in 1997, but fluctuated more than proved reserves of crude oil or natural gas (Table 2). Production of natural gas liquids since 1980 was 431 million barrels.

Wyoming has remaining discovered and undiscovered resources of approximately 5.7 billion barrels of oil, 4.5 billion barrels of natural gas liquids, and 176.3 trillion cubic feet of natural gas (U.S. Geological Survey National Oil and Gas Resource Team, 1995). These resources are technically recoverable, but not all are economically recoverable at the present time. The oil, natural gas liquids, and natural gas resources include proved reserves, reserve growth in conventional fields, undiscovered conventional resources, and continuous-type accumulations in sandstones, shales, chalks, and coal beds. Among the states, Wyoming has 5.1 % of the remaining oil, 15.4 % of the remaining natural gas liquids, and 16.4 % of the remaining natural gas. Almost 60 % of the oil resources are located or will be discovered in the Powder River Basin. Most of the rest of the oil is located or will be found in the Bighorn and Wind River basins (Figure 5). About 96 % of Wyoming's natural gas liquids and natural gas resources are located in or will be discovered in the Overthrust Belt, the Green River Basin, the Great Divide Basin, and the Washakie Basin (Figure 5).

COAL

Wyoming's recorded coal production started in the 1860s, but until the 1970 Clean Air Act (CAA), the state's coal production remained stagnant at under 5-million short ton/year (mty). In 1969 the total production of Wyoming's coal mines was only 4.606 mt. The 1970 CAA limit on SO_2 emissions stimulated an explosion of mine development in Wyoming's Powder River Coal Field, starting in 1972 when the state's coal miners broke the 10 mty barrier. Today Wyoming mines have crossed the 300 mty milestone and are projected to reach the 365 mty mark by 2005 (Figure 1).

In 1997, 92.3% or 259.8 mt of coal produced in Wyoming came from the Wyodak coal zone (Paleocene Fort Union Formation) in the eastern Powder River Coal Field. While the mined portions of the zone consist of one to three beds of coal with an aggregate thickness between 50 and 110 feet (ft), the thickest expression is 200 ft. The delivered coal from this zone averages 0.33% sulfur, 5.12% ash, and 8,590 Btu/lb. (Glass, and Lyman, 1998).

In the Powder River Basin, coal beds occur in rock sequences deposited during either the Late Cretaceous Epoch (81 to 66.4 million years ago) or during the Paleocene or Eocene Epochs (66.4 to 36.6-million years ago) of the younger Tertiary Period. These Wyoming coals are young when compared to the 266-320 million-year-old coals that occur in the Pennsylvanian Period in the midcontinent and eastern coalfields of the U.S.

The Cretaceous peat deposits (precursors to the coal) were most often located in deltaic, coastal plain, or other nearshore settings along a Cretaceous epeiric seaway. The Tertiary coals accumulated as fresh-water peats at a time when crustal downwarping formed the basin and regional uplift caused the epeiric seaway to withdraw from the Powder River Basin area of Wyoming. Tertiary peat swamps were associated with fluvial and fluvio-lacustrine depositional systems rather than with any marine influences (Glass, 1977; Moore and Shearer, 1993).

Due to the contrasting tectonic and sedimentary settings under which Cretaceous and Tertiary coal beds formed, the Cretaceous coals are generally more laterally extensive, thinner, and higher in sulfur (> 1%) than the Tertiary coals (Glass, 1977; Moore and Shearer, 1993). These latter two differences partially explain why the Cretaceous coals are not currently mined in the Powder River Coal Field.

The remaining demonstrated strippable reserve base of the Wyodak coal bed is the largest for any single coal bed in Wyoming and perhaps for any coal bed in the U.S. This remaining reserve base is an estimated 16.5 billion short tons (bt), of which 12.7 bt is compliant coal (modified from Jones and Glass, 1992). For comparison, the strippable reserve base for the Wyodak coal bed is almost 74% of the remaining strippable reserve base in the Powder River Coal Field and 65% of the remaining strippable reserve base for Wyoming. Production and mining losses from the Wyodak coal zone through 1997 have totaled more than 3.1 bt and most of that production has occurred since 1972. Production from this coal bed was 259.8 mt in 1997.

Wyoming's remaining discovered and undiscovered resources of coal are an estimated 1,458 bt. Wood and Bour (1988) estimated that Wyoming's Powder River Coal Field contained 1.03 trillion short tons of original in-place coal resources. Of this resource, the remaining demonstrated strippable reserve base in the coalfield is an estimated 22.3 bt (modified from Jones and Glass, 1992). Of that, an estimated 13.2 bt is compliant coal, i.e., containing 0.6 or less pounds of sulfur

per million Btu. The estimate of the remaining strippable reserve base in the Powder River Basin is very conservative because it is based on an overburden cut-off of only 200-ft. The remaining strippable reserve base is likely more than double the current estimate.

LIQUIDS FROM COAL AND SOLID FUELS FROM COAL

Into the 21st century, two currently developed processes will aid in the economic utilization of Wyoming's coal resources. KFx's process to form upgraded coal (K-Fuel) from Powder River Basin coals involves a decarboxylation process. The resultant fuel is a clean, stable fuel that is essentially anhydrous. The K-Fuel has upward of 40% more heating value per pound than its feedstock coal. The LFC process, being introduced by ENCOAL, is a process which produces hotter and cleaner burning coal, oil, and gas, from low grade coal feedstock (mine waste coal). The process causes thermal fraction of coal by mild pyrolysis, and uses a controlled temperature regimen adjusted to the feed coal's properties. Reduced ash, 1/3 less NO_x and 1/2 the SO_2 emissions will help these sorts of emerging technologies come of age.

COALBED METHANE

Production of coalbed methane, derived from the Wyodak coal zone, is currently occurring just west and downdip from the coal mines on the outcrop and is increasing each year. Coalbed methane was first recognized and used in the Powder River Basin in 1916, when a rancher began using gas coming out of his water well. That well, located on a ranch near the Montana state line, apparently produced desorbed coalbed methane from a sandstone reservoir (Olive, 1957).

The first commercial venture in Wyoming that produced methane directly from a coal bed was development of the Rawhide Butte field. The wells were completed in the Wyodak coal at a depth of 400 to 500 ft. The coal bed is up to 140 ft. thick (Jones and DeBruin, 1990). The discovery of this field was directly related to surface seepage of methane gas into a housing development. Rawhide Village subdivision, located about nine miles north of Gillette and only a few miles from the Rawhide coal mine, was evacuated when methane was discovered in residents' backyards and basements as well as in the streets (Jones and others, 1987; Jones and Taucher, 1989).

In 1998, production of coalbed methane from the Wyodak coal zone in the Powder River Basin was about 56.2 million cubic feet per day or 20.5 billion cubic feet for the year (Figure 6). Production could more than triple by 2005, when the number of online wells will increase and additional pipeline capacity will be available. In regard to reserves, it is conservatively estimated that the Powder River Basin of Wyoming and Montana contains 30 tcf of recoverable coalbed methane (Ayers and Kelso, 1989).

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Figure 1. Annual coal production from Wyoming (1985-1998) with forecasts to 2005 (millions of tons). Source: Wyoming State Geological Survey Coal Section.

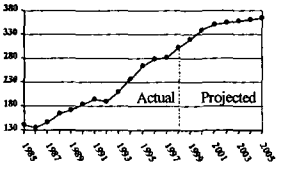

Figure 2. Annual production of Wyoming natural gas from 1980 to 1998 with forecasts to 2005 (billions of cubic feet). Source: Wyoming Oil and Gas Conservation Commission.

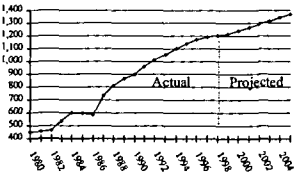

Figure 3. Annual production of Wyoming natural gas liquids from 1980 to 1998 with forecasts to 2005 (millions of barrels). Source: Wyoming Oil and Gas Conservation Commission.

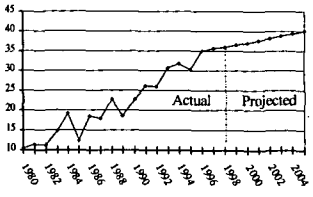

Figure 4. Annual production of Wyoming crude oil from 1980 to 1998, with forecasts to 2005 (millions of barrels). Source: Wyoming Oil and Gas Conservation Commission.

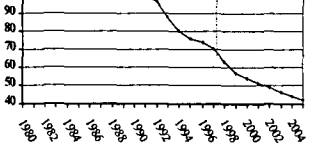

Figure 6. Annual production of Wyoming coalbed methane from 1987 to 1998, with forecasts to 2005 (billions of cubic feet). Source: Wyoming Oil & Gas Conservation Commission.

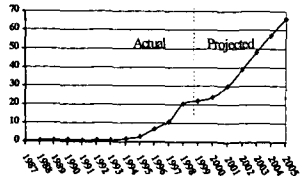

Figure 5. Index map of Wyoming basins and ranges.

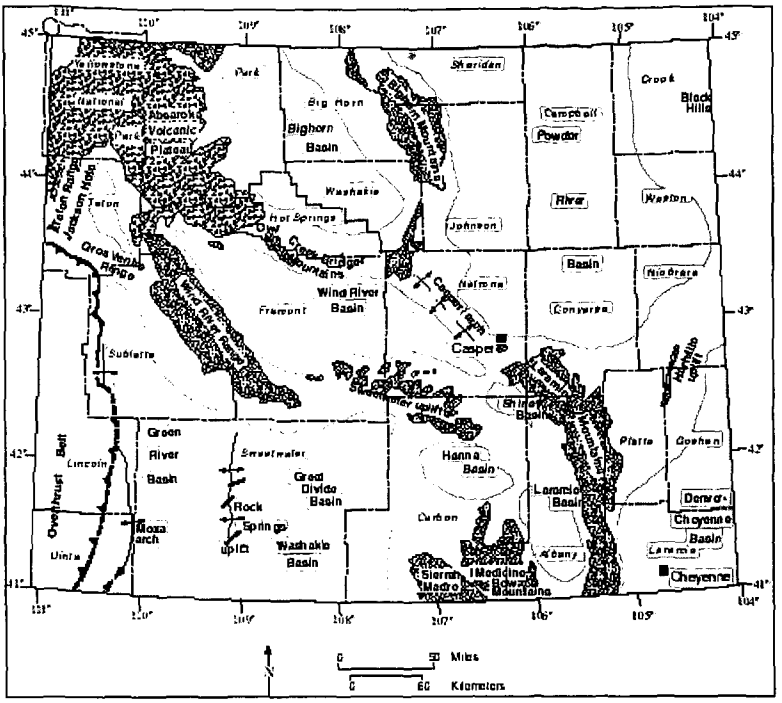

Table 1. Wyoming's ranking in proved reserves of crude oil (billions of barrels), dry natural gas (trillions of cubic feet), and natural gas liquids (billions of barrels) at the beginning of 1998.
Source: U.S. Department of Energy, 1998

State	Crude Oil	State	Dry Natural Gas	State	Natural Gas Liquids
Texas	5.687	Texas	37.761	Texas	2.687
Alaska	5.161	New Mexico	15.514	New Mexico	0.869
California	3.750	Wyoming	13.562	Oklahoma	0.685
New Mexico	0.735	Oklahoma	13.439	Alaska	0.631
Louisiana	0.714	Alaska	10.562	Wyoming	0.600
Wyoming	0.627	Louisiana	9.673	Louisiana	0.437
Oklahoma	0.605	Kansas	8.989	Kansas	0.271
North Dakota	0.279	Colorado	8.828	Colorado	0.264
Kansas	0.238	Alabama	4.968	Utah	0.181
Utah	0.234	West Virginia	2.846	California	0.095

Table 2. Comparison of Wyoming's proved reserves of crude oil (billions of barrels), dry natural gas (trillions of cubic feet), and natural gas liquids (billions of barrels) for the years 1980 through 1997.
Source: U.S. Department of Energy, 1998

Year	Crude Oil	Dry Natural Gas	Natural Gas Liquids[1]
1980	0.928	9.100	0.239
1981	0.840	9.307	0.269
1982	0.856	9.758	0.477
1983	0.957	10.227	0.552
1984	0.954	10.482	0.602
1985	0.951	10.617	0.684
1986	0.849	9.756	0.565
1987	0.854	10.023	0.647
1988	0.625	10.308	0.808
1989	0.815	10.744	0.627
1990	0.794	9.944	0.568
1991	0.757	9.941	0.524
1992	0.689	10.826	0.462
1993	0.624	10.933	0.420
1994	0.565	10.789	0.395
1995	0.605	12.166	0.415
1996	0.603	12.320	0.505
1997	0.627	13.562	0.600

[1] Estimated from U.S. Department of Energy figures